Paleoseismic Investigation of Earthquake Hazard and Long-term Movement History of the Hurricane Fault, Southwestern Utah and Northwestern Arizona

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INVESTIGATIONS UNDERTAKEN

The Utah Geological Survey (UGS) and the Arizona Geological Survey (AZGS) have undertaken a one-year study of the Hurricane fault, the longest and most active of several large, late Cenozoic, west-dipping normal faults in the transition zone between the Colorado Plateaus and Basin and Range physiographic provinces in southwestern Utah and northwestern Arizona. The purpose of the study is to develop new paleoseismic information that will help characterize the fault's late Quaternary behavior, test current segmentation models, and provide information critical to earthquake-hazard assessment in a rapidly urbanizing region. The UGS scope of work includes: (a) conducting a paleoseismic trenching investigation at one or more sites on the northernmost segment (Ash Creek segment: Stewart and Taylor, 1996) of the fault, and (b) developing long-term fault-slip data from displaced basalt flows in Utah. The AZGS is focusing on the Shivwits segment of the fault in Arizona (Pearthree and others, 1998) and is conducting a geologic reconnaissance at key points along the segment to determine long- and short-term fault slip rates.

Utah Geological Survey Investigation

Trenching: Results of a joint 1997 AZGS and UGS National Earthquake Hazards Reduction Program (NEHRP) grant (Award Number 1434-HQ-97-GR-03047) to investigate paleoseismicity and seismic hazard in southwestern Utah and northwestern Arizona identified five additional sites on the Ash Creek segment where fault scarps are formed on unconsolidated deposits (Pearthree and others, 1998). Only one site, at Shurtz Creek, was previously known (Averitt, 1962; Anderson and Christenson, 1989). Two of the new sites (Water Tank and Kannarraville) are south of a large right bend in the fault at Murie Creek, one site is at the bend (Murie Creek), and two sites (Bauer and Middleton) are north of the bend (Fig1.).

The UGS considered all six locations for trenching and selected the Murie Creek site as the preferred alternative. The Murie Creek site includes an approximately 3-meter-high, likely single-event scarp formed on a probable Holocene-age alluvial fan and a 10-meter-high, multiple-event scarp formed on colluvium at the base of the Hurricane Cliffs. We expected trenching to provide information on the timing and size of the most recent surface-faulting earthquake and one or more preceding events. Access is excellent at Murie Creek and the scarps are formed on fine to moderately coarse material that is easily excavated. However, the site is on private property, and while the landowner was willing to allow surface investigations at the site (scarp profiling and soil test pits), he refused repeated requests to allow backhoe trenching and a request to hand-excavate a trench across the single-event scarp. There appears little likelihood that the landowner will reconsider his decision.

Re-evaluation of the remaining five sites resulted in the selection of the scarp at Shurtz Creek ((Fig 1.) for trenching. This site has the advantage that all of the displacement on the fault in late Quaternary time is confined to a single, large (12 m) scarp formed on alluvium, and the site is on public land where trenching is permitted. We originally rejected Shurtz Creek because the ground surface is covered with large boulders, some as much as 2 meters in diameter, which we thought might extend into the subsurface, and because access to the site is through a dense forest with no roads. Trenching at Shurtz Creek commenced in early September using a large trackhoe with a 4-foot-wide bucket. We immediately encountered large boulders in the subsurface which limited the trench to less than a meter and a half deep and prevented exposing the fault zone. Moving to a new location along the scarp was rejected because we had already selected what we considered to be the most likely site (fewest boulders) and because access problems were prohibitive.

In the absence of a viable trench site on the north end of the Hurricane fault, our efforts there will now focus on dating unfaulted young stream alluvium that overlies the fault zone immediately adjacent to scarps formed on older alluvium at the mouths of washes in the Hurricane Cliffs. Dating the alluvium will provide a minimum age for the timing of the most recent faulting event at the north end of the fault.

Developing Long-term Fault-slip Data from Displaced Basalt Flows

The UGS is using petrologic, geochemical, and paleomagnetic data to make definitive correlations of displaced basalts across the Hurricane fault and to determine the amount of back-tilting toward the fault for net-slip calculations. We will use $^{40}Ar/^{39}Ar$ radiometric dating to determine the age of the displaced basalts and the time period over which the slip occurred. Dr. Michael Hozik of the Richard Stockton College of New Jersey is performing the paleomagnetic analysis; Professor Stanley Hatfield of Southern Utah University is doing the petrologic and geochemical study.

Paleomagnetic analysis: Differences in the orientation of the remanant magnetic vector between basalts in the hanging wall and foot-wall (if any) provide a measure of the back-tilting of the hanging wall toward the fault. Paleomagnetic characteristics can help correlate basalt flows across the fault (normal versus reversed polarity), and determine their ages within broad categories (normal polarity flows have ages < 780,000 years, reversed polarity flows have ages between 780,000 years and 1.2 million years). Additionally, the magnetic susceptibility anisotrophy of the flows gives an indication of flow direction and hence the direction to the source of the lava. This is an important consideration along the Hurricane fault because flows originating east of the fault may owe a portion of their separation across the fault to cascading over a pre-existing scarp.

Field work for the paleomagnetic study is complete. Dr. Hozik sampled (drilled) a total of 42 sites in displaced and/or back-tilted basalts collecting a total of 437 basalt cores for paleomagnetic analysis. The sample sites are located in five principal areas(Fig2.): (a) Deadman Hollow where basalt flows crop out on top of the Hurricane Cliffs and apparently correlative flows crop out in the adjacent hanging wall, (b) Pintura area where a series of stacked basalt flows occupy an embayment about two-thirds of the way up the Hurricane Cliffs and apparently correlative flows crop out in the hanging wall farther to the southwest, (c) Toquerville area where basalt flows crop out in the foot-wall at the south end of Black Ridge and in the hanging wall in Ash Creek Canyon,

(d) Virgin River area where basalt flows crop out along State Route 59 in the foot-wall and apparently correlative flows crop out in the canyon of the Virgin River, and (e) Grass Valley area south of the town of Hurricane where Sanchez (1995) tentatively correlated basalt on the fault foot-wall with flows in the hanging wall in Grass Valley.

Petrologic and geochemical study: Field work for the geochemical and petrologic evaluation and correlation of displaced basalts being conducted by Professor Hatfield is also complete. Professor Hatfield collected 114 samples for geochemical and petrologic analysis from 57 sites along the Hurricane fault between the Kolob Section of Zion National Park and the Arizona State line. He and Dr. Hozik coordinated their sampling and located all their sample sites using global positioning satellite technology.

Approximately half of the samples have been sent for thin section preparation with an expected completion date of November 15, 1999. The remaining samples will be sent in late November and examination of thin sections will commence as soon as the sections are received. Most of the geochemical samples have been sent to the analytical laboratory for major, minor, and trace element analyses and all remaining geochemical samples will be shipped by November 5, 1999. Results from the geochemical analyses are expected by early December. Interpretation of the petrologic and geochemical data will begin in December with an expected February completion date.

$^{40}Ar/^{39}Ar$ age determinations: We have collected samples for $^{40}Ar/^{39}Ar$ age determinations from several potentially key paleomagnetic and geochemical/petrologic

sample locations along the fault. The samples actually submitted for age determination will be selected once correlations of the basalts displaced across the Hurricane fault are made based on the paleomagnetic, geochemical, and petrologic data now being developed.

Arizona Geological Survey Investigation

The AZGS is investigating the seismic behavior on the Shivwits section of the Hurricane fault in Arizona. Only the extreme northern end of the Shivwits section was studied in the recently completed AZGS/UGS paleoseismic investigation. Preliminary analysis of fault-scarp profiles measured along the Shivwits segment suggests that the age of the youngest rupture is somewhat older than on sections of the fault to the north (Pearthree and others, 1983; Stenner and others, 1998). The AZGS is conducting a detailed reconnaissance of the Quaternary geology and structural geology along the Shivwits segment. We are identifying locations of relatively low scarps along the base of the Hurricane Cliffs that record late Quaternary fault activity. Most of the scarps appear to be quite high and are formed near the bases of steep colluvial slopes, and it may be possible to deduce something about fault slip rates and scarp age from the morphologies of these scarps. Based on photointerpretation, we have identified a locality where late Quaternary faulting has displaced a stream terrace that slopes much less steeply than adjacent colluvial slopes. This appears to be the most promising site for fault trenching, which will be conducted in the spring of 2000. We plan to (1) survey topographic scarp profiles at several localities along the fault, (2) describe carbonate-rind development on faulted alluvial landforms to estimate late Quaternary slip rates, and (3) excavate a trench to determine fault displacement in the youngest surface rupture in the central part of the Shivwitz section and hopefully to constrain the time of youngest surface faulting.

RESULTS

Utah Geological Survey Results:

Results of UGS trenching at the north end of the Hurricane fault are inconclusive. Landowner restrictions at our preferred site and large boulders and limited access at our alternate site prevented excavation of a trench that exposed the fault zone. The remaining four sites along the Ash Creek segment with scarps formed on alluvium are poor candidates for a paleoseismic trench study and we consider the likelihood extremely low of obtaining useful paleoseismic information at any of those sites. No additional trenching is planned unless the landowner on whose property the Murie Creek scarps are located reconsiders and allows us to trench there. Further efforts to constrain the timing of late Quaternary earthquakes on the northern portion of the Hurricane fault will consist of trying to date unfaulted alluvium that overlies the fault zone at the mouths of drainages that are adjacent to scarps formed in older alluvial deposits. Dating the unfaulted deposits will provide a minimum limiting age for the most recent surface-faulting earthquake.

Completed paleomagnetic laboratory work

Hanging wall and foot-wall near Toquerville

The paleomagnetic data are: hanging wall-15 samples (from 4 flows), declination = 119.2°, inclination = -55.4°, 95 = 4.2°; footwall-20 samples (from 6 flows), declination = 164.0°, inclination = -64.0°, 95 = 4.4°. These data suggest that the hanging wall has been rotated 25° toward the fault (reverse drag) since the extrusion of the lava. Reversed magnetic vectors require these lavas to be older than 780,000 years.

Hanging wall and footwall near Hurricane

The paleomagnetic data are: hanging wall-15 samples (from one flow), declination = 342.6°, inclination = 50.1°, 95 = 5.9°; footwall-17 samples (from 2 flows), declination = 345.5°, inclination = 59.0°, 95 = 2.7°. The similarity of these orientations suggests a maximum of 10° reverse drag on the hanging wall. Sanchez (1995) reported an $^{40}Ar/^{39}Ar$ age of 353,000 years for those flows, which is consistent with the magnetic data.

Ash Creek North (hanging wall north of Toquerville, but south of Leap Creek)

The paleomagnetic data are: 11 samples from 2 or 3 flows (correlations are unclear), declination = 145.42°, inclination = - 46.04°, 95 = 4.0°. The reversed magnetic vectors require these lavas to be older than 780,000 years. They may well correlate with flows on top of Black Ridge, although that is not proven. The orientation of this magnetic vector suggests less rotation due to reverse drag than farther south near Toquerville. These conclusions should be regarded as tentative, as there are more samples from this locality that could alter the results.

Ash Creek Interstate (hanging wall north of Leap Creek)

The paleomagnetic data are: 5 samples from 1 flow, declination = 157.0°, inclination = -57.1°, 95 = 3.4°.Correlation of displaced basalt flows based on geochemical and petrologic data is awaiting laboratory results. No definitive conclusions regarding the correlation of basalt units can be made based solely on field work. Some possible patterns have been observed from our sample collection and examination of basalt flows, but reliable correlations await completion of the petrologic and geochemical analyses.

Arizona Geological Survey Results:

Work completed by the AZGS to this point is a detailed analysis of 1:24,000-scale aerial photographs of the Shivwitz section. We have identified locations of relatively low scarps along the base of the Hurricane Cliffs that record late Quaternary fault activity. Most of the scarps appear to be quite high and are formed near the bases of steep colluvial slopes. It may be possible to deduce something about fault slip rates and scarp age from the morphologies of these scarps (see Stenner and others, 1999). We have identified at least one locality where late Quaternary faulting has displaced a stream terrace that slopes much less steeply than adjacent colluvial slopes. This appears to be the most promising site for fault trenching, which will be conducted in the spring of 2000.

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NON-TECHNICAL SUMMARY

The Utah Geological Survey and the Arizona Geological Survey have begun a cooperative research project to evaluate earthquake hazards on the long, active Hurricane fault in southwestern Utah and northwestern Arizona. In Utah, we tried unsuccessfully to trench the fault to obtain information on the size and timing of prehistorical earthquakes. Future efforts there will focus on dating unfaulted stream deposits that directly overlie the fault. The most recent surface-faulting earthquake must be older than those deposits. We are also working out the long-term (past approximately one million years) slip history of the Hurricane fault by studying the chemical, mineral, and magnetic characteristics of basalt flows displaced across the fault. We will date the flows that are the same on both sides of the fault by measuring the rate of decay of radioactive minerals in the rock. The age of the basalts and the amount they are displaced will allow us to calculate an average slip rate (displacement/time) for the fault. In Arizona, we plan to survey fault scarp profiles at several localities along the fault, describe soil development on faulted deposits to estimate slip rates, and excavate a trench to determine fault displacement in the youngest surface rupture in the central part of the Shivwitz section and to determine the time of youngest surface faulting.

REPORTS PUBLISHED:

No reports based on this work have been published as of this time.

AVAILABILITY OF INFORMATION

Contact William R. Lund at (435) 865-8126, lund@suu.edu for information regarding the various kinds of data being generated by this project.